# Complex Responses of High-Elevation Forests in the Sierra Nevada to Climate Change

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## Subalpine and Alpine Zones

Considered among the most threatened ecosystems, highly sensitive to climate

### Assumption

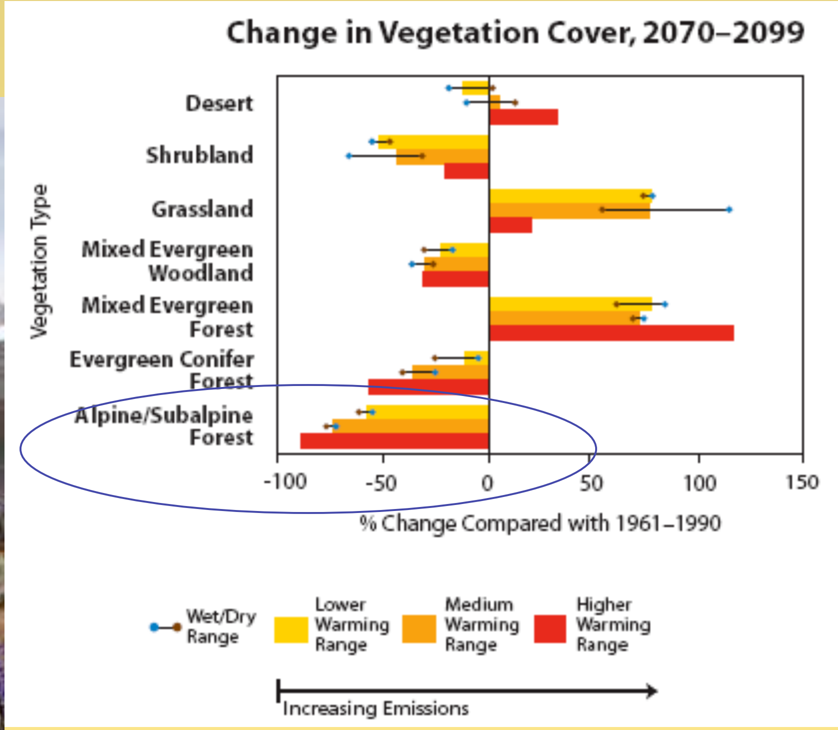
Vegetation (species and communities) responds to rising temperatures by moving up in elevation; Available area diminishes with elevation

# Upper Elevation Forests

Treeline elevation incorporated into regional warming models.

**Prediction**: Alpine and subalpine species and communities "go to heaven"

Global warming threatens alpine and subalpine ecosystems, which have no place to move as temperatures rise.




From: CCCC. 2006. Our Changing Climate; Assessing the Risks to California

Hayhoe et al. 2004 *PNAS* 101: 12422-12427

# Premise

Uphill migration is one likely response to rising temperature but not the only response

Species in the alpine and subalpine zone respond to climate complexly and individualistically

# I. **FOREST DENSIFICATION** (without significant change in treeline)

## A. General Subalpine Forest Infilling

1907 1984

E of Tioga Pass (TPR)

Vale & Vale. 1994. Time & the Tuolumne Landscape

Gruell. 2001. Fire in Sierra Nevada Forests

Gaylor Pk & West Flank Mt Dana, YNP

1907

1984

Vale & Vale. 1994. Time & the Tuolumne Landscape

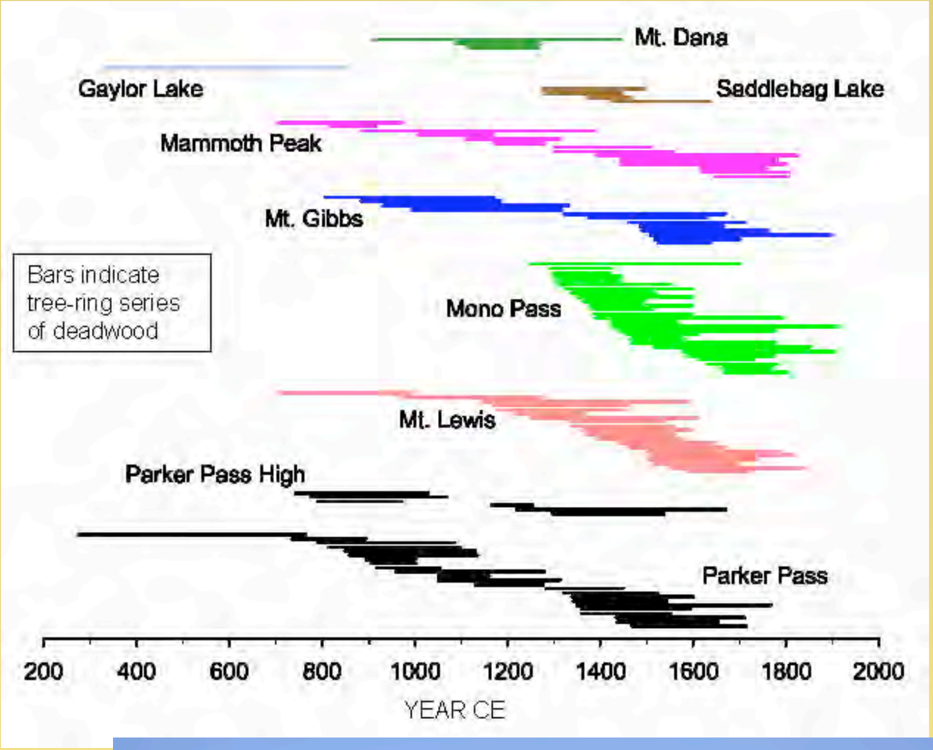
# I. **FOREST DENSIFICATION** (without significant change in treeline)

## B. Treeline Zone Infilling

Whitebark pine (*Pinus albicaulis*)

Mt Warren

Mammoth Crest



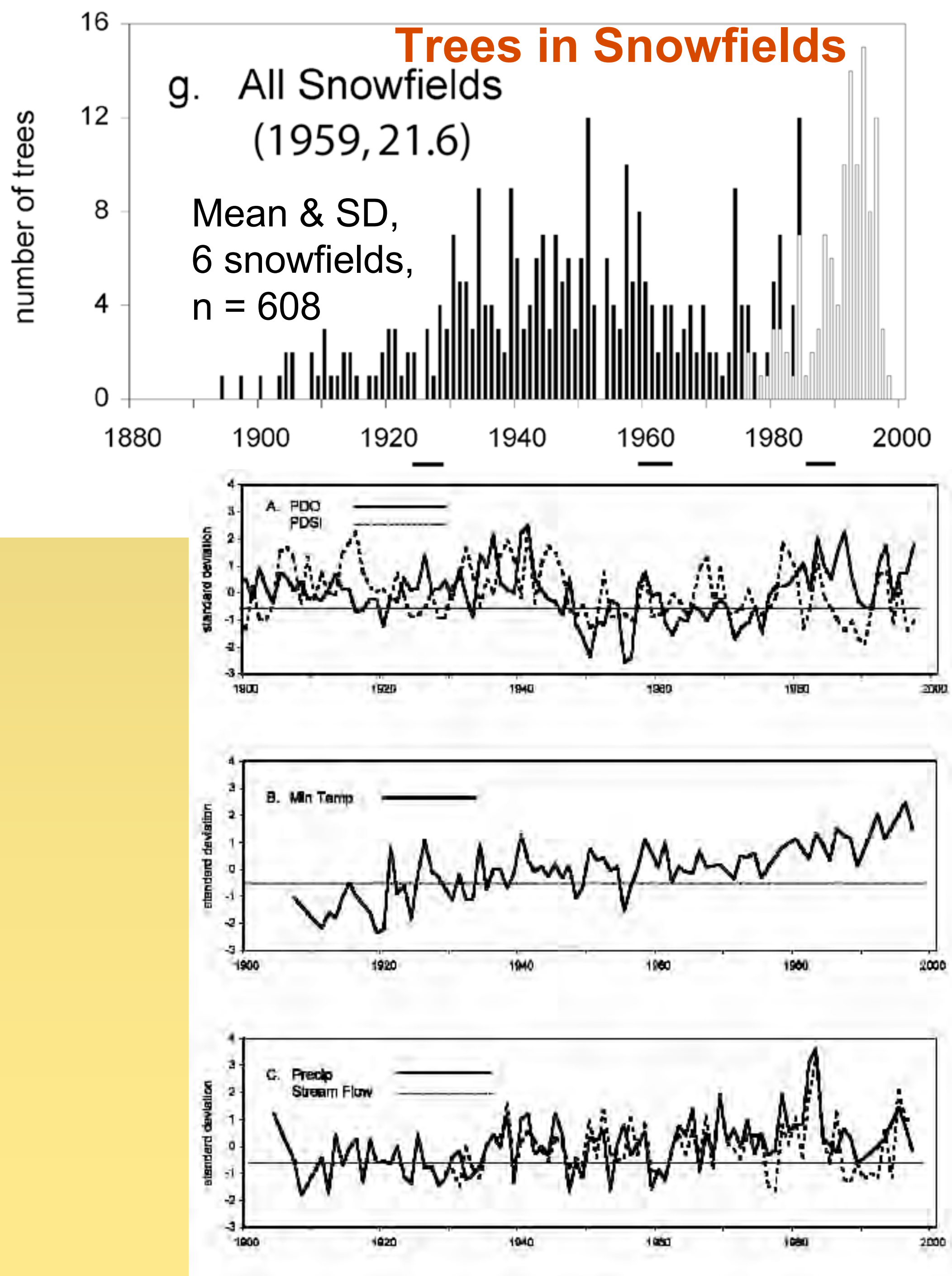

- Krummholz individuals persist to 1700 years by vegetative rooting compared to upright tree longevity < 500 yrs
- Deadwood scattered within live zone but not higher – treeline stable

King & Graumlich. 1999
Rogers, Millar, & Westfall. 1999

## I. **FOREST DENSIFICATION** (without significant change in treeline)

### C. Colonization of Formerly Persistent Snowfields

## Trees in Snowfields




# Primary response is to temperature

Millar, Westfall et al. 2004

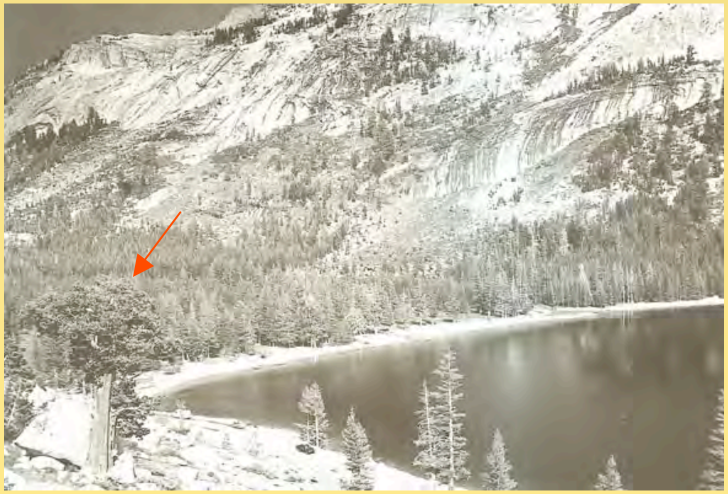
# I. **FOREST DENSIFICATION** (without significant change in treeline)

## D. Colonization of Subalpine Meadows

Tuolomne Mdws, YNP 2006

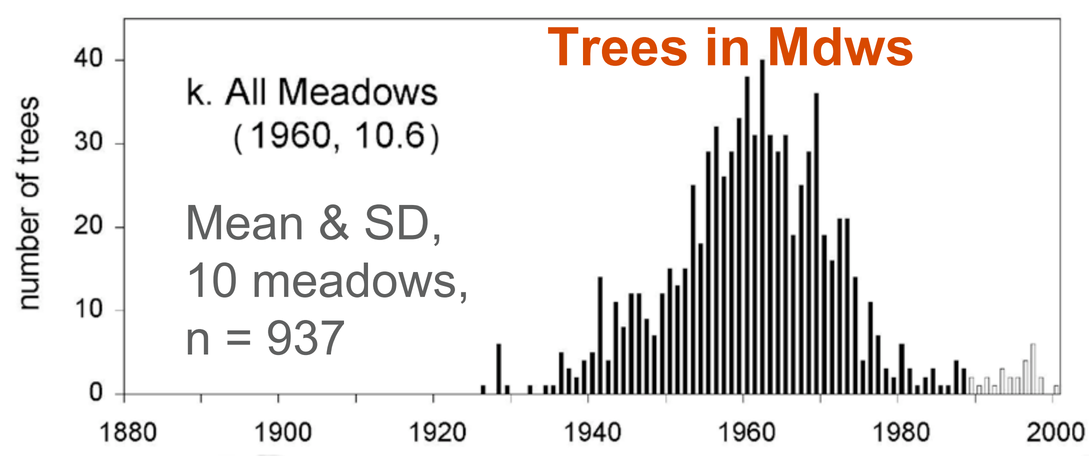
1907

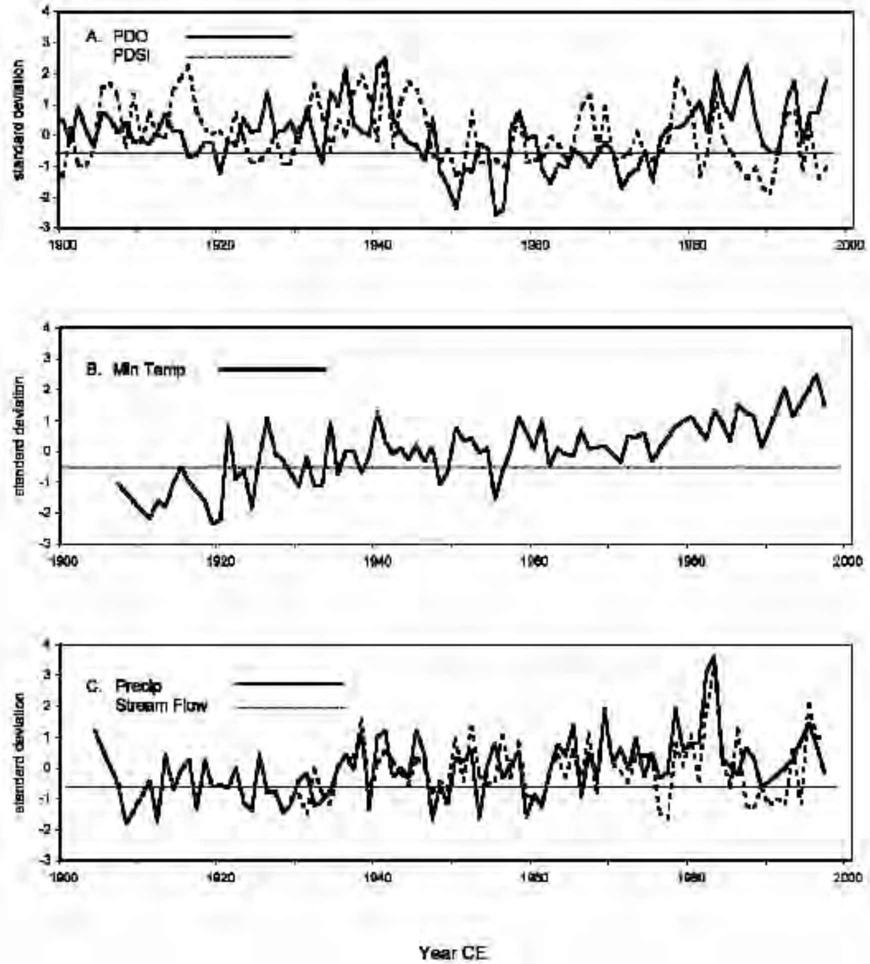
1984



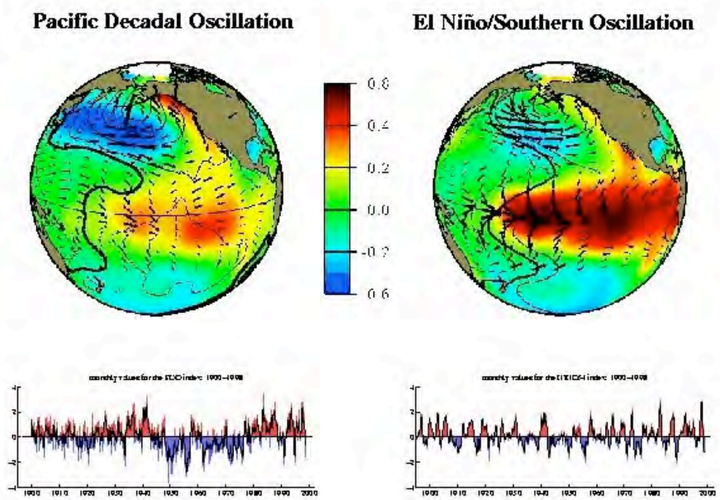
Tenaya Lk

Vale & Vale. 1994. Time & the Tuolumne Landscape



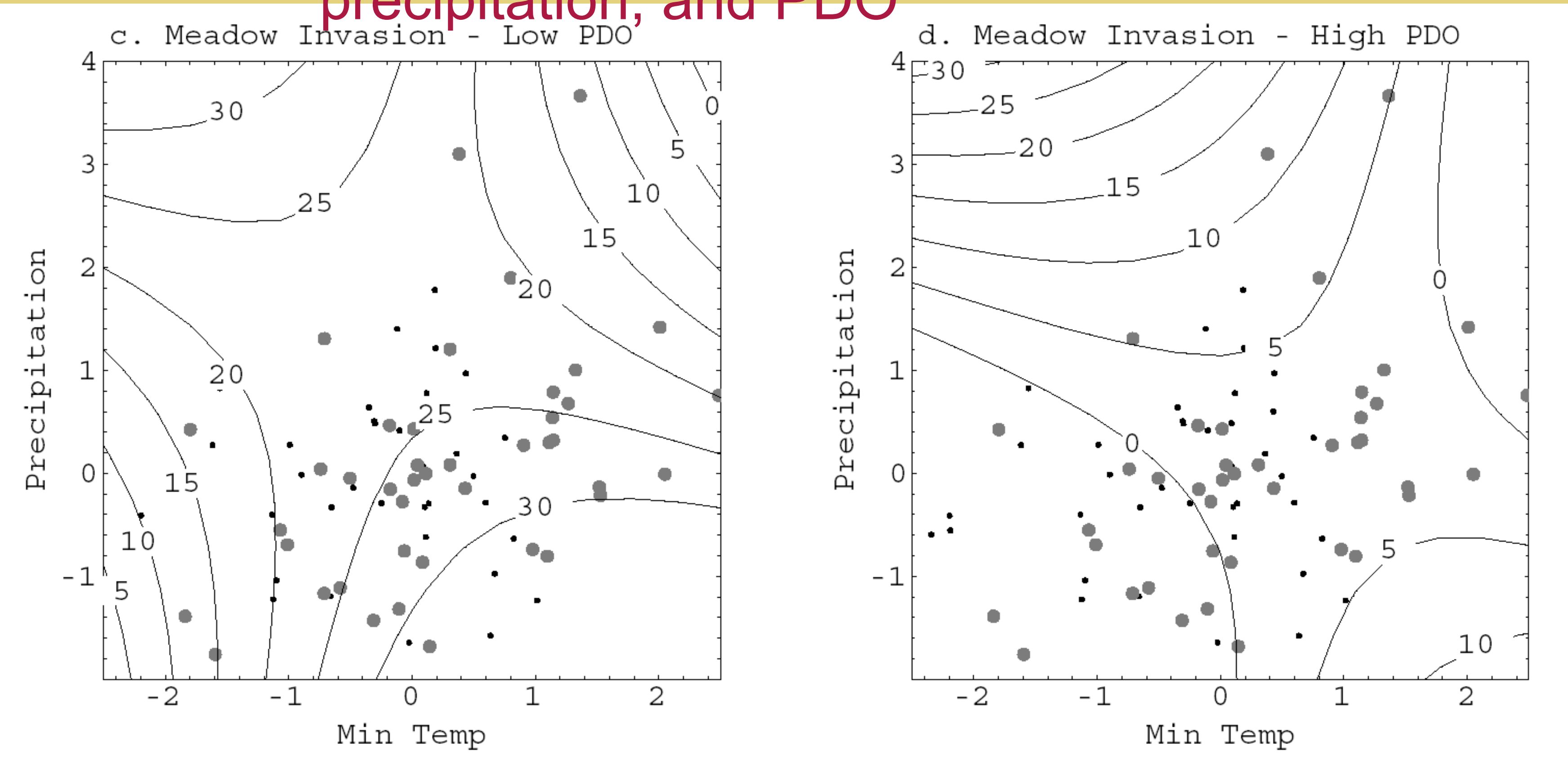




# Primary response to warming and - PDO




Millar, Westfall, et al. 2004

# Complex interactions of colonization, temperature, precipitation, and PDO




Contour intervals are in units of ecological response. Main axis units are SD's from mean of the variable. Scatter of dots is the set of recorded points from 90-yr weather record, large dots indicate positive PDO and small dots negative PDO

Millar, Westfall, et al. 2004

# Meadow colonization is readily reversible




Pothole Dome,
Tuolomne Mdws, YNP

Vale & Vale. 1994

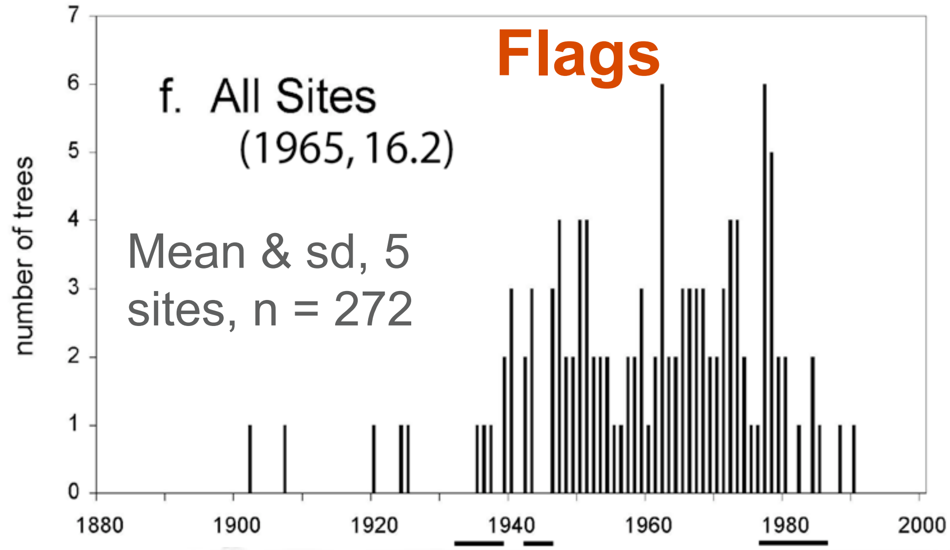
# II. CHANGE IN FORM & GROWTH
## (without significant change in treeline)

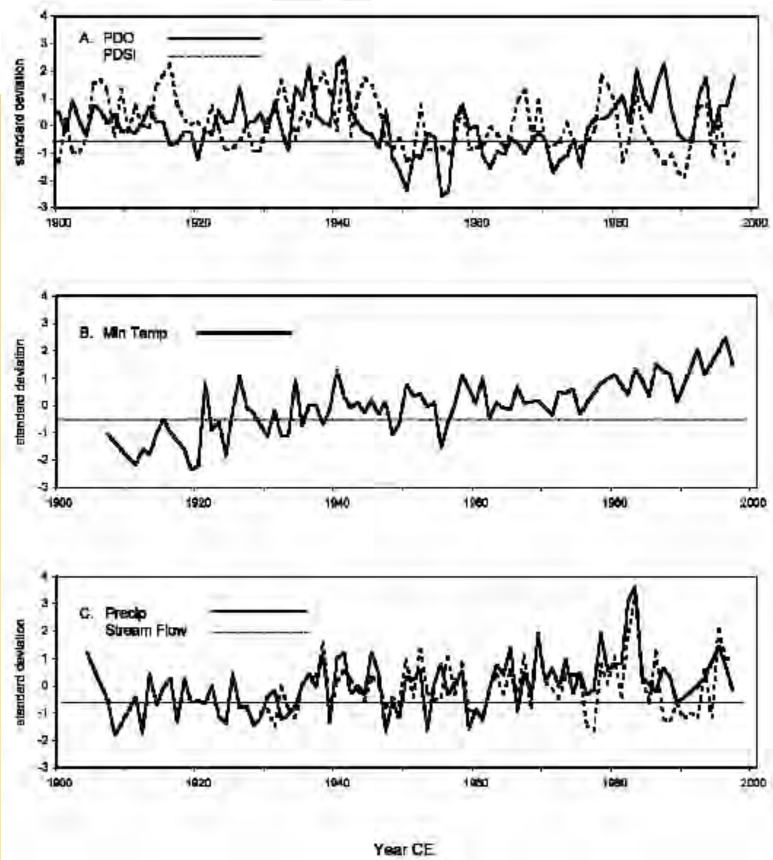


Whitebark pine (*Pinus albicaulis*), the sublime subalpine species

Harsh conditions prune whitebark pine into krummholz form

Milder conditions favor persistence of flags and growth of upright stems



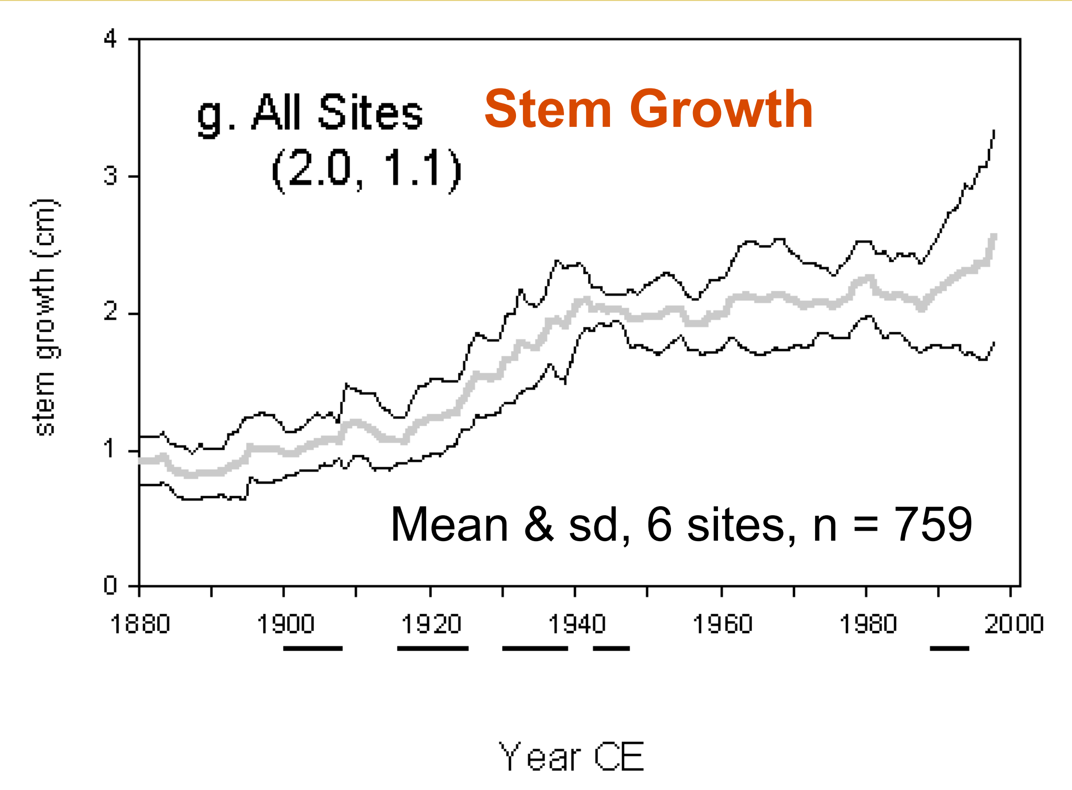

Development of upright flags responds to temperature and PDO

Similar to meadow colonization, flag response is reversible

Millar, Westfall, et al. 2004

# Stem growth in krummholz whitebark pine near treeline doubled over the 20th century






Parker Pass, Kuna Pk, YNP

Vale & Vale. 1994

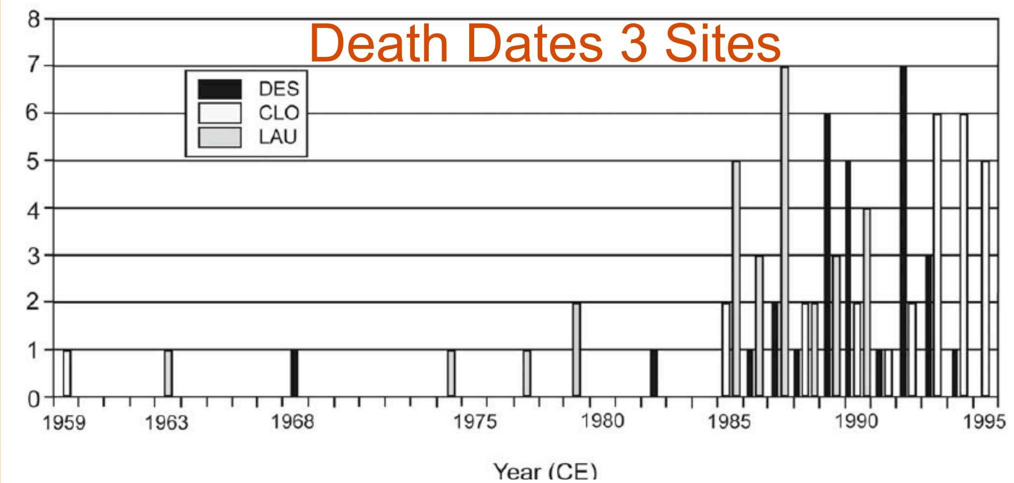
Millar, Westfall, et al. 2004

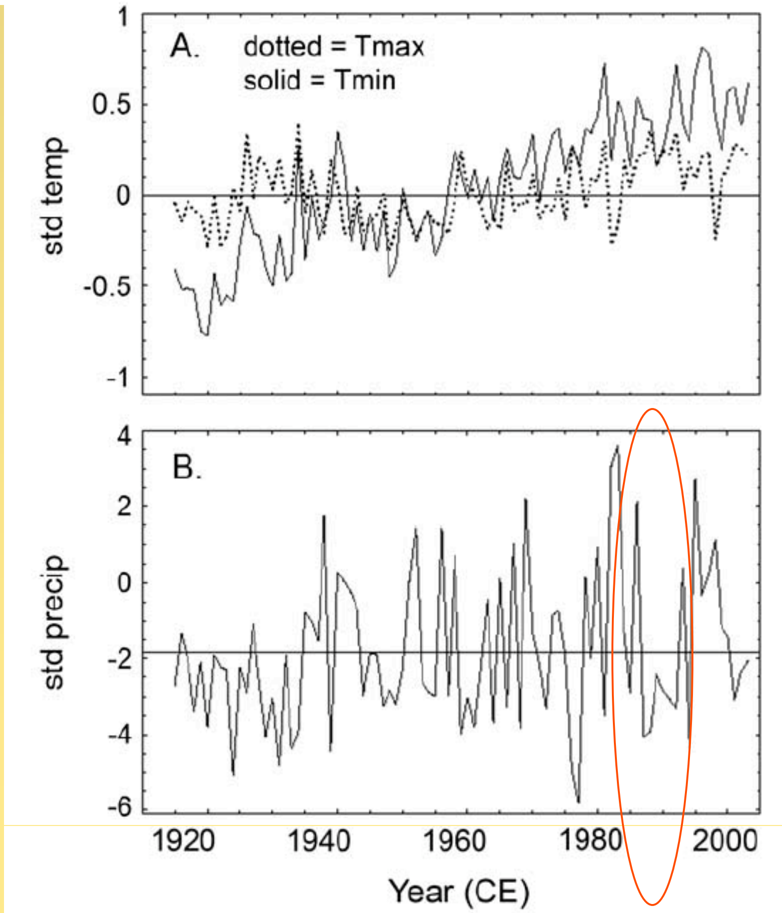
# III. CHANGE IN PATTERNS OF MORTALITY
(without significant change in treeline)

## A. Change in Drought and Insect & Disease Effects

Mortality event in subalpine limber pine (*Pinus flexilis*)

Mt Warren, Mono Basin




1988-1995 drought
+ elevated temperatures
+ mountain pine beetle
+ mistletoe infection
= mortality event in limber pine

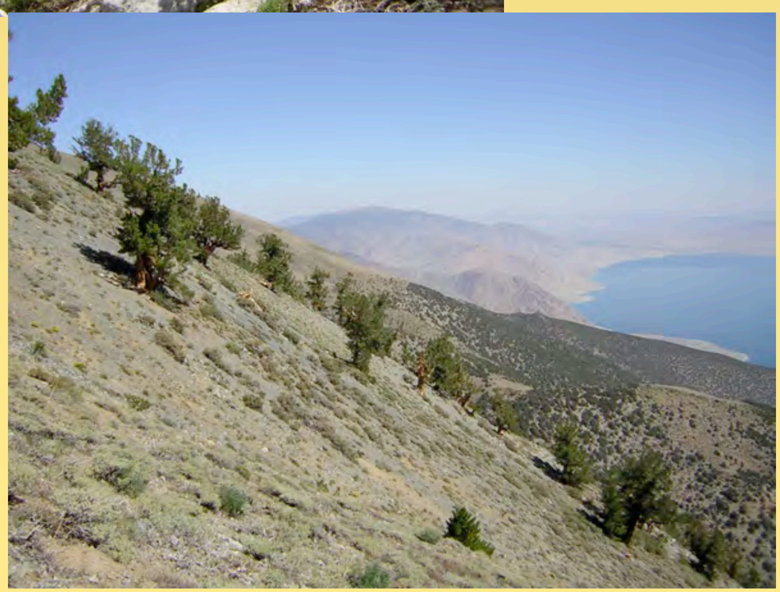
Millar, Westfall, Delany. in review

# III. CHANGE IN PATTERNS OF MORTALITY
## (without significant change in treeline)

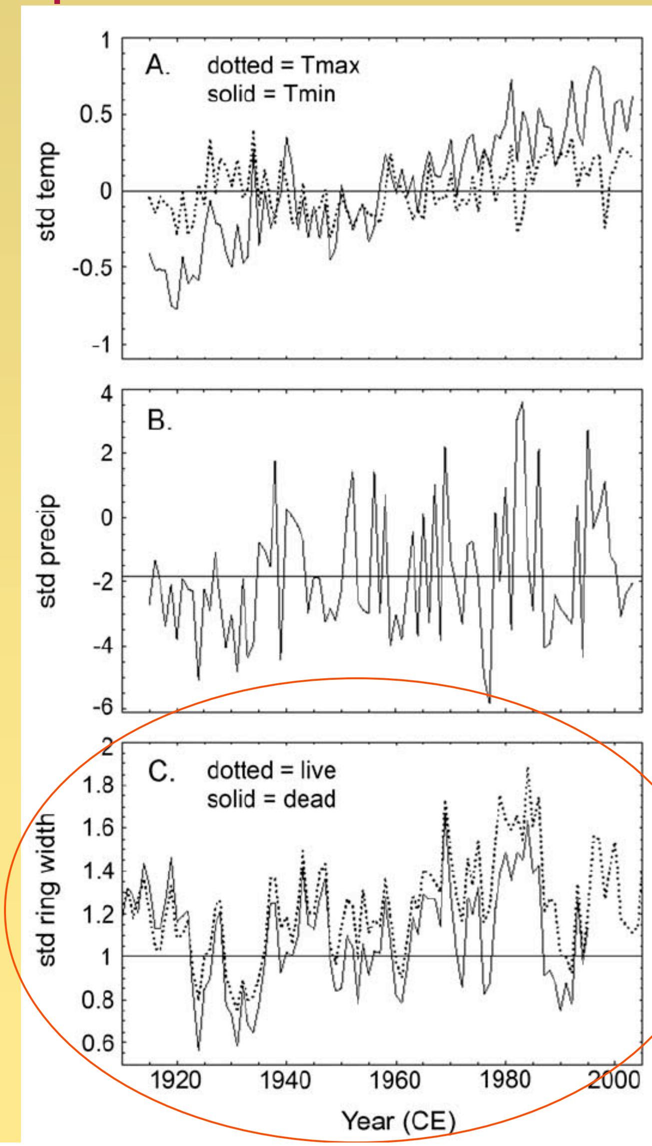
### B. Change in Genetic Diversity & Adaptation

Millar, Westfall, Delany. In review

Live trees remain



Typical sparse old-growth limber pine stand, Mt Grant



# III. CHANGE IN PATTERNS OF MORTALITY
(without significant change in treeline)

C. Change in Subalpine Zone Fire Relationships

Cascade Crest Complex, OR August 2006
High elevation pine forests

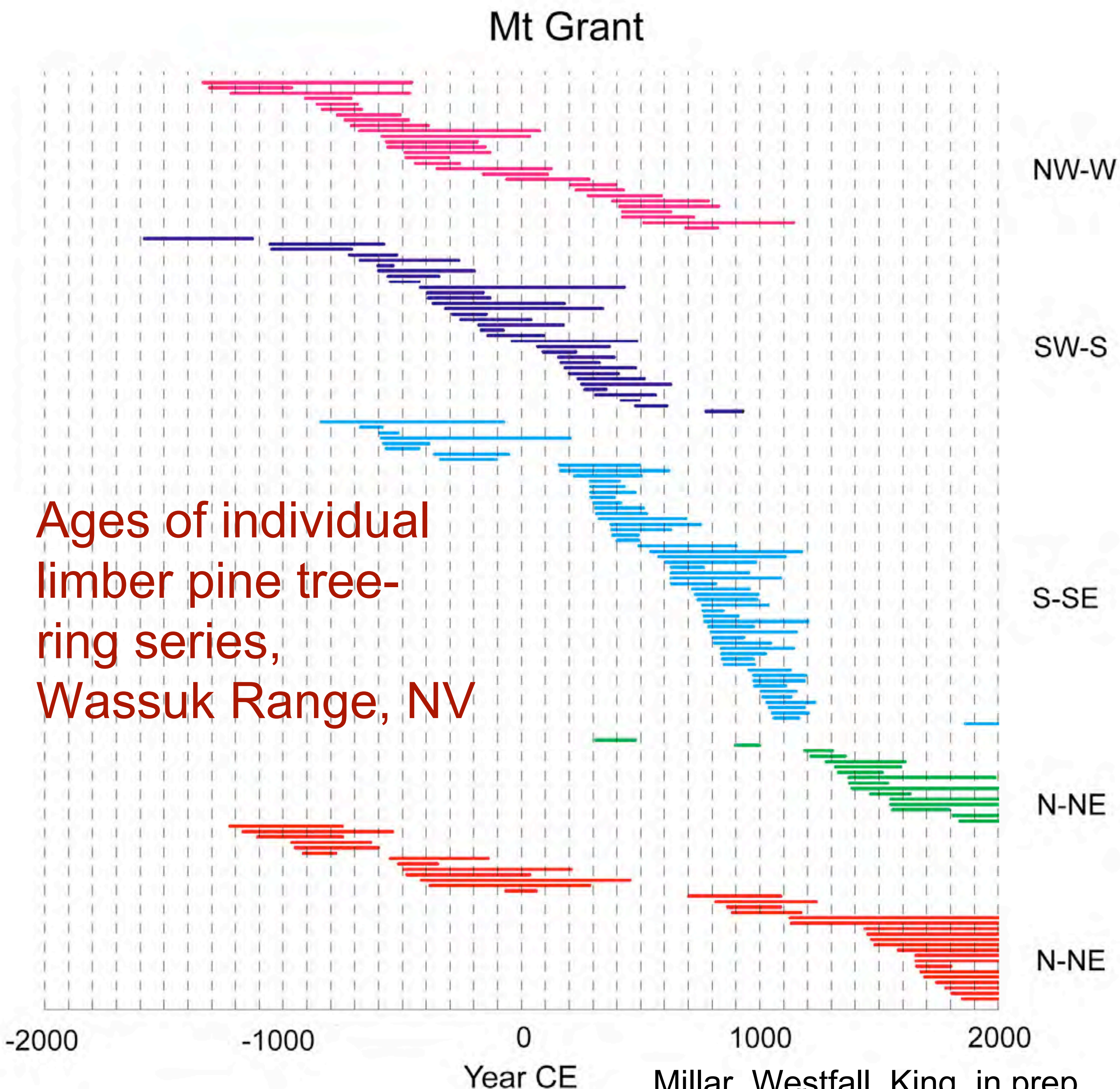
# **IV. CHANGE IN ASPECT** (without significant change in treeline)

Limber pine, E Sierra Nevada, SW Great Basin

Sparse live stands on N/NE aspects

Mt Grant, Wassuk Range

Abundant deadwood throughout drainages on other aspects




Ages of individual limber pine tree-ring series, Wassuk Range, NV

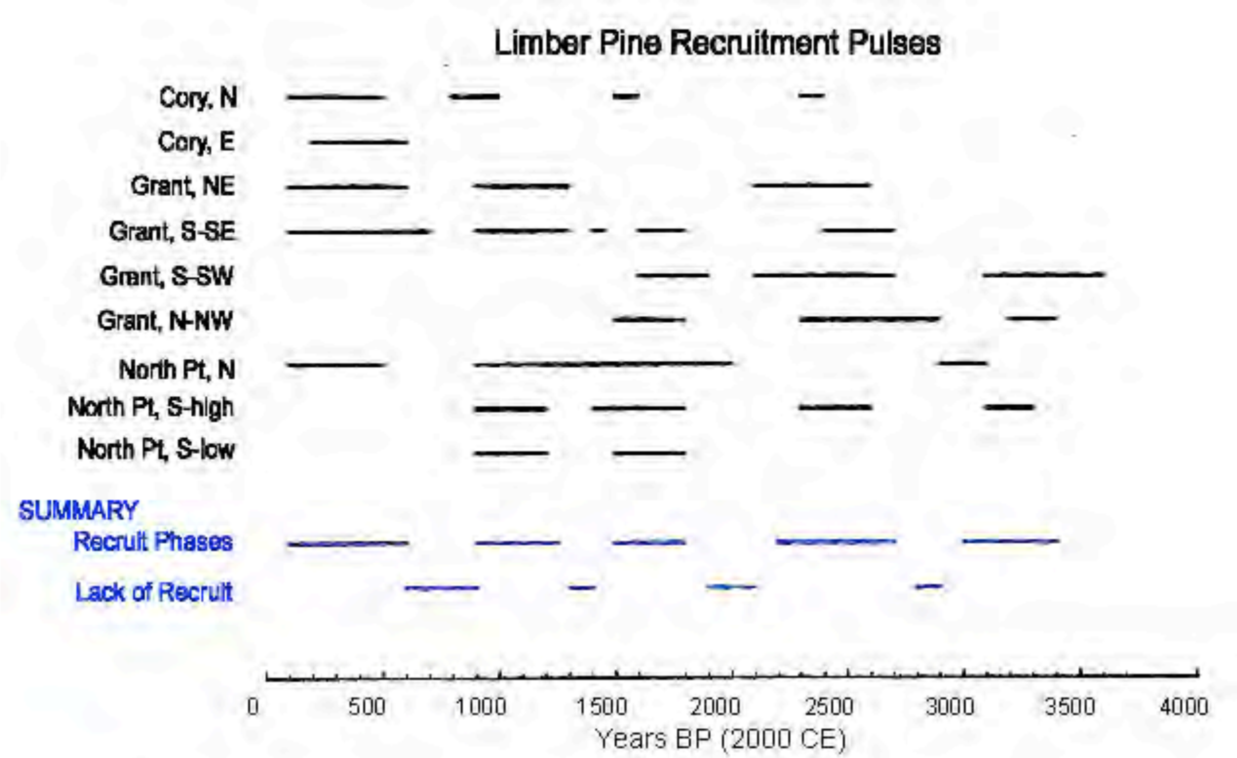
Millar, Westfall, King, in prep

## Upper and lower elevation extents (m) of live *Pinus flexilis* trees & deadwood on different aspects

| Stand | Aspect | Dead High | Live High | Dead Low | Live Low |
|---|---|---|---|---|---|
| GR | N/NE | 3190 | 3222 | 2944 | 2682 |
| RC | SE/E/NE | 3200 | 3178 | 2700 | 2700 |
| DC | N/NE | 3086 | 2990 | 2819 | 2819 |
| LP | W/NW/N | 3151 | no live | 3048 | no live |
| CN | W/NW | 3178 | no live | 2993 | no live |
| LG | W/NW | 3109 | no live | 3004 | no live |
| GR | S/SW | 3139 | no live | 2915 | no live |
| NC | S/SE | 3210 | 3033 | 2621 | 2621 |
| CC | NE/E | 2774 | 2774 | 2665 | 2665 |

Range: Live High 2774 – 3222m, Low 2621 – 2819m
Dead High 2774 – 3210m, Low 2621 – 3048m

Elevations are not greatly different, live vs dead over 3500 years in limber pine forests on Mt Grant




Drought Periods, YBP, identified by proxies other than limber pine:

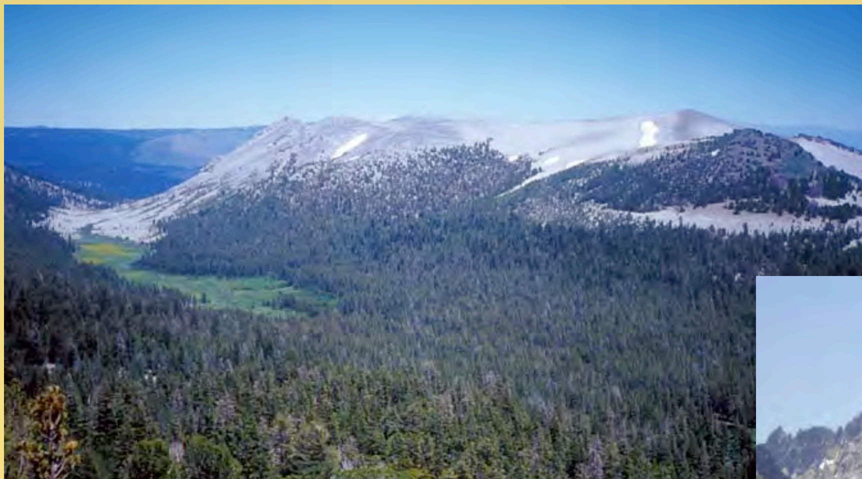
| | |
|---|---|
| 600-800: | Stine, Walker, Pyramid, Mono, Owens, Tree Rings, Springs, Pinyon |
| 1300-1400: | Walker, Pyramid, Pinyon |
| 1400-2100: | Pyramid, Springs, Pinyon |
| 2100-2700: | Walker |
| 2800-2900: | Pyramid |

Millar, Westfall, King, in prep

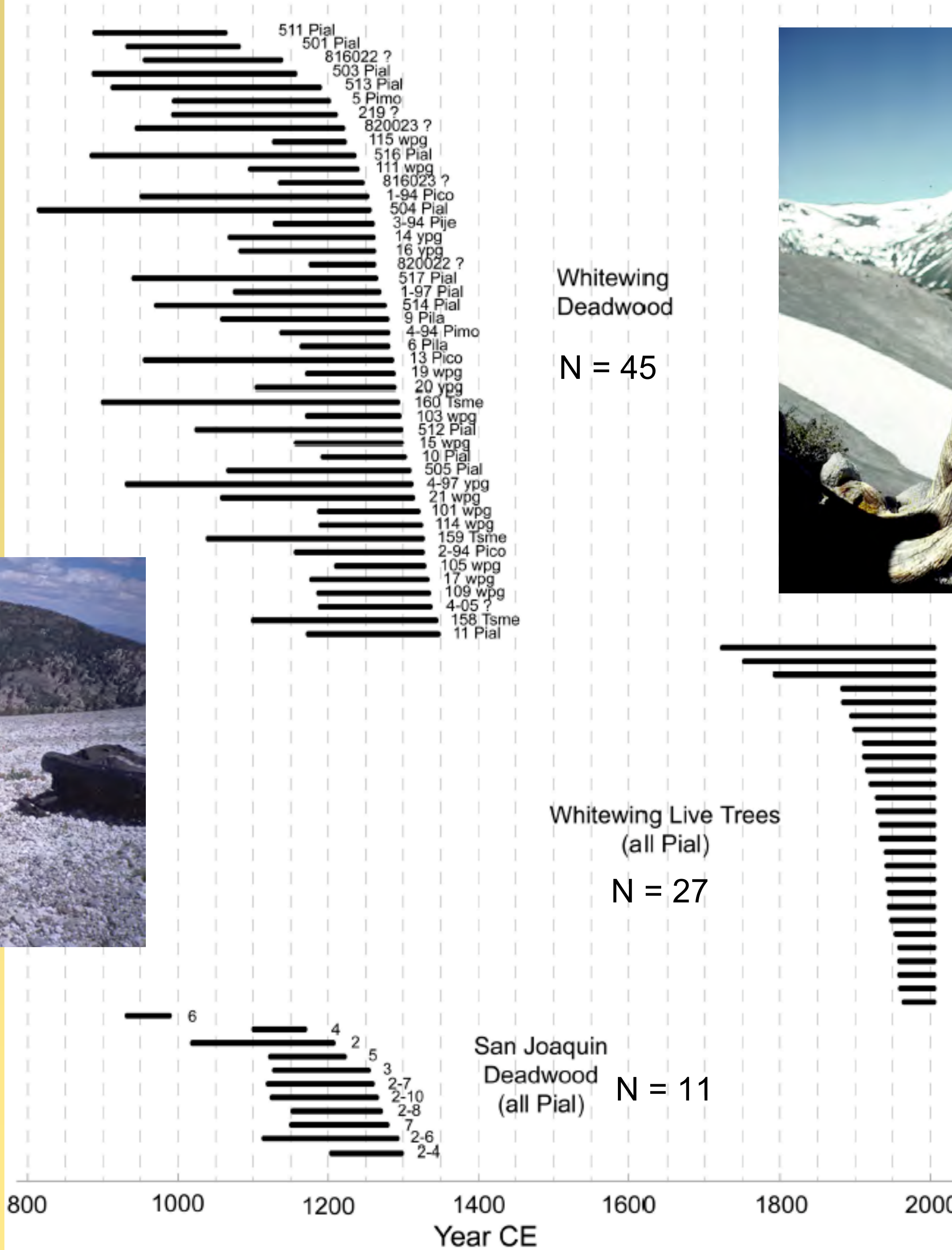
# V. CHANGE IN ELEVATION

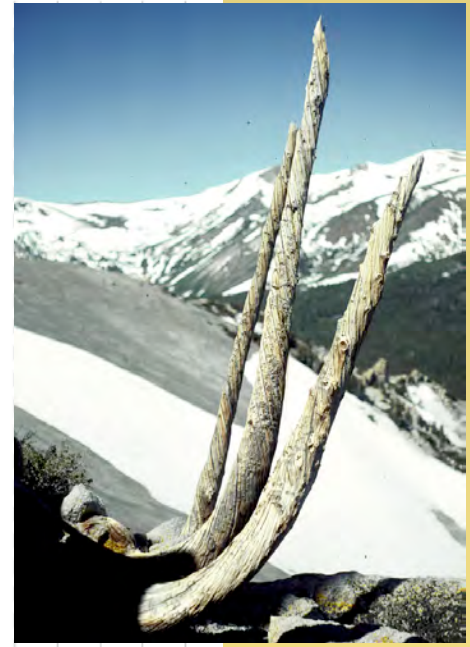
## A. Differential Shifts in Elevation – Individualistic Response

*Example 1: Whitewing Mtn and San Joaquin Mtn, ESN*



# Deadwood Stem Dates



Millar, Westfall, et al.
In press

# Deadwood Species

42 Whitebark Pine krumm

13 W White Pine ↓250 m

7 Lodgepole Pine ↓250 m

5 Jeffrey Pine ↓500 m

6 Mountain Hemlock ↓250 m

5 Sugar Pine & W SN

# Current and paleo-historic climate estimates as modeled from PRISM and discriminant analysis

| Location | Ann ppt (mm) | July ppt (mm) | Jan ppt (mm) | Ann min temp (°C) | Jan min temp (°C) | July min temp (°C) | Ann max temp (°C) | Jan max temp (°C) | July max temp (°C) |
|---|---|---|---|---|---|---|---|---|---|
| **A. Current climate: 1971-2000 CE** | | | | | | | | | |
| San Joaquin Ridge | 945 | 5 | 195 | -4.5 | -9.8 | 3.4 | 10.9 | 0.7 | 21.2 |
| Whitewing Mtn | 1064 | 14 | 184 | -3.7 | -10.0 | 3.6 | 11.0 | 1.4 | 21.5 |
| **B. Paleoclimate: 800-1350 CE** | | | | | | | | | |
| Whitewing Mtn | 1040 | 13 | 186 | -0.5 | -6.5 | 7.6 | 13.3 | 4.6 | 24.1 |
| **C. Difference in Whitewing Mtn Climate Values** | | | | | | | | | |
| Paleo – Current | -24 | -1 | +2 | +3.2 | +3.5 | +4.0 | +2.3 | +3.2 | +2.6 |

Compare with:

*Hayhoe et al., 2004. PNAS 101:12422-12427*

| 1961-1990 | 2020-2049 | 2070-2099 |
|---|---|---|
| Change in ave temp °C | 1.4 to 2.0 | +2.3 to 5.8 |
| Change in ave precip mm | | |
| Annual | -70 to +6 | -157 to +38 |
| Winter | -55 to +4 | -92 to +13 |
| Change in Apr 1 snowpack % | | |
| 2,000 – 3,000 m | -36 to -24 | -93 to -22 |
| Change in Ap-Jn Resv inflow % | | |
| Northern Sierra | -16 to -24 | -47 to -6 |
| Loss subalpine forests % | 50 to 75 | 75 to 90 |

# V. CHANGE IN ELEVATION

## A. Differential Shifts in Elevation

*Example 2: Recruitment of Bristlecone Pine (BCP) and Limber Pine (LP), White Mtns, CA*

Upper Elevation Sites (3350 – 3566 m; current BCP treeline 3500 m)
Recruit Classes: Abundance ranges from entirely LP to 5:1 LP-BCP

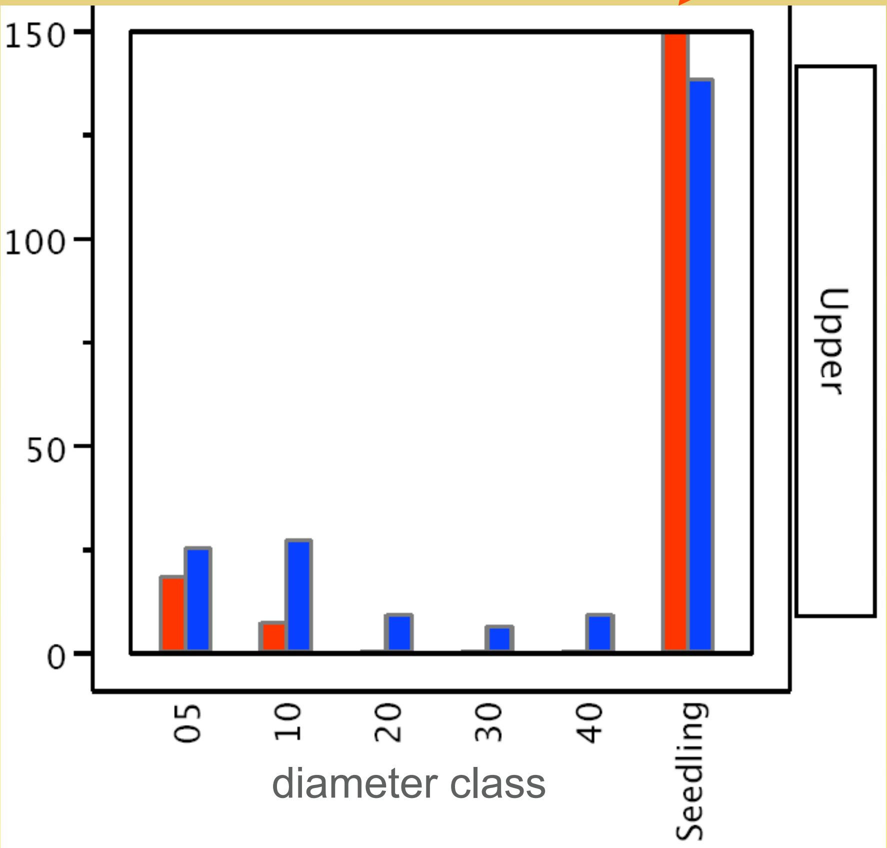
Upper Cottonwood Cr, 3566 m

Campito Mtn, 3444 m

# Three Treeline Sites, White Mtns

Red = Limber pine Blue = Bristlecone pine

Limber pine seedlings >500

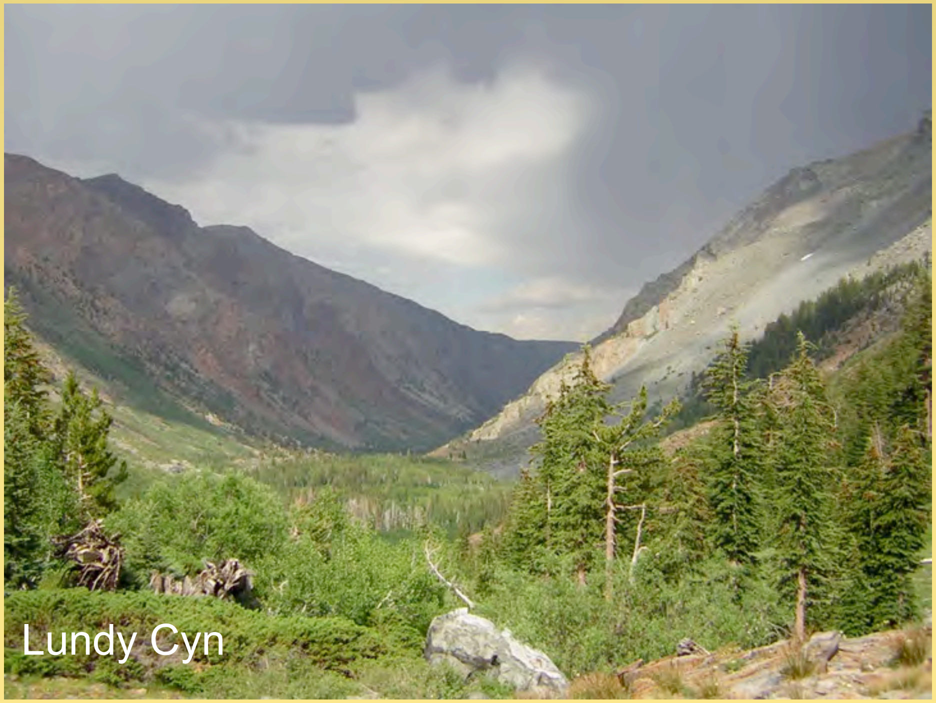



Seedling class is 5-30 yrs old (1986-2002);
5-10” Limber Pine class is 45-65 yrs old (1941-1961)

# V. CHANGE IN ELEVATION

## B. Shifts Down in Elevation with Warming and Drying

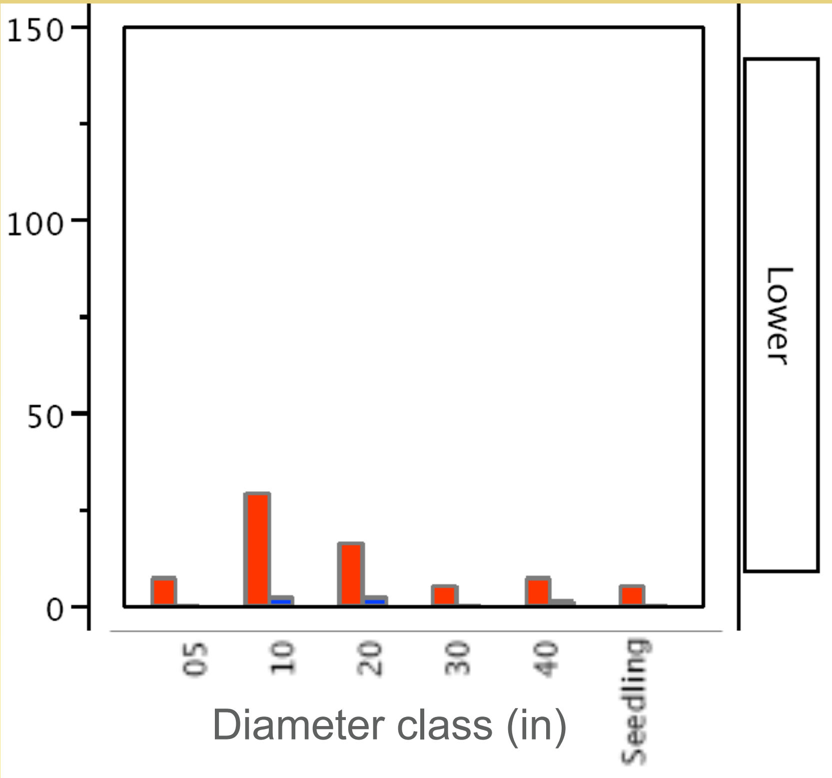
Narrow and deep canyons provide cool, wet refugial habitats;
Paleo-studies suggest downhill movement during long droughts

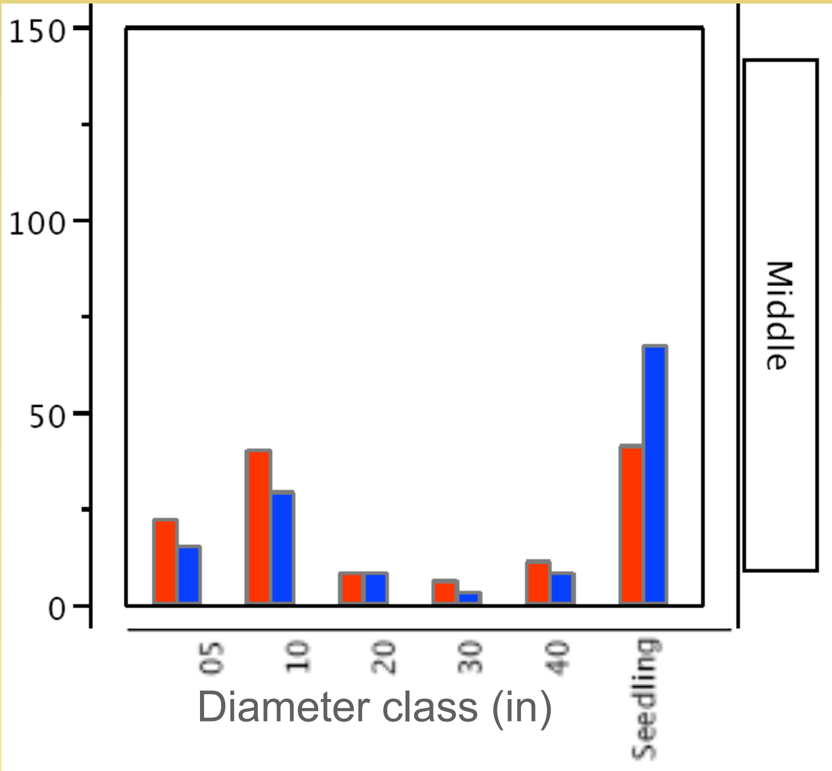



Limber and Bristlecone Pines are recruiting below lower treeline in westslope ravines (2950 m), and downslope into sagebrush basins (3070 m), White Mtns

# Three Treeline Sites, White Mtns

Red = Limber pine Blue = Bristlecone pine

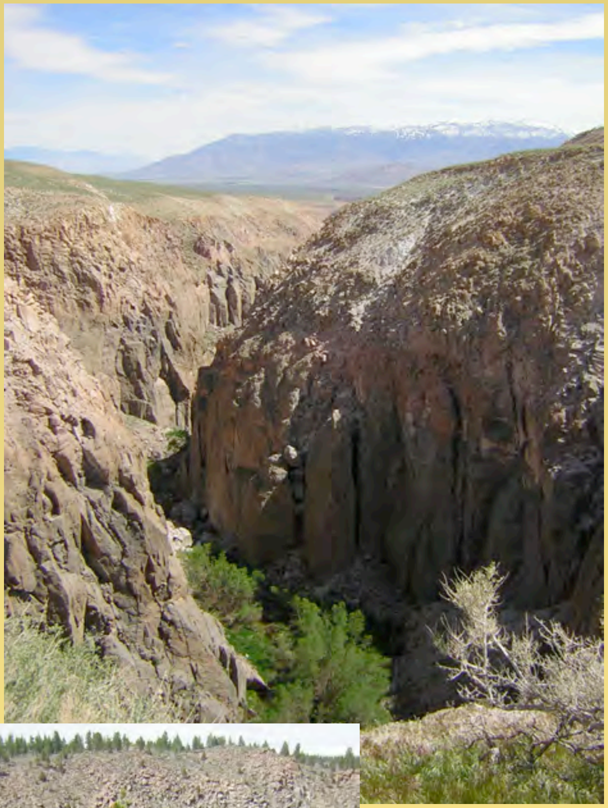



Seedling Class 5-30 yrs old

# Other Examples of Lower Treeline 20th-21st Century Recruitment in Limber Pine

Ravines down to 2530 m, Glass Mtn, Long Valley



Owens River Gorge, E SN down to 1950 m

# V. CHANGE IN ELEVATION

## C. Synchronous Shifts Up in Elevation with Warming

Foxtail pine (*Pinus balfouriana*)

Western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta*), and mountain hemlock (*Tsuga mertensiana*)

Note that there is considerable high-elevation area > 3500 m in the Sierra Nevada = old elevated surfaces

# Summary *Responses of Subalpine Species to Climate*

## I. Forest Densification (no treeline change)

A. General Subalpine Forest Infilling
B. Treeline Zone Infilling
C. Colonization of Formerly Persistent Snowfields
D. Colonization of Subalpine Meadows

## II. Change in Growth & Form (no treeline change)

## III. Change in Patterns of Mortality (no treeline change)

A. Change in Drought and Insect & Disease Effects
B. Change in Genetic Diversity & Adaptation
C. Change in Fire Relationships

## IV. Change in Aspect (no treeline change)

## V. Change in Elevation (with treeline change)

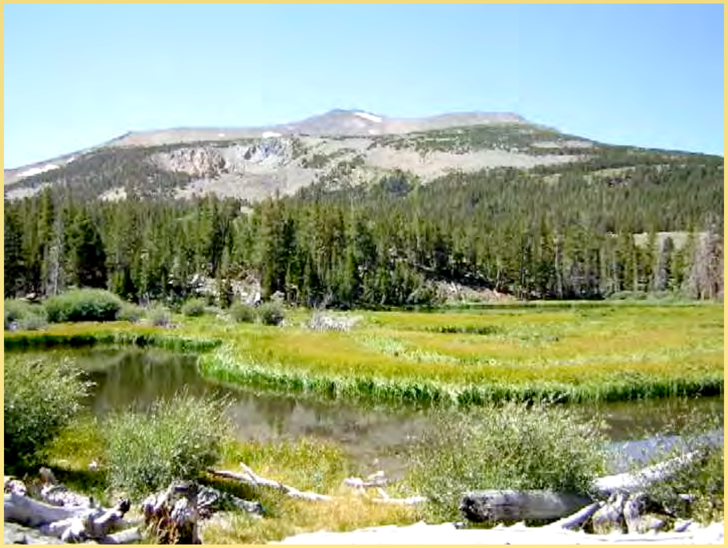
A. Differential Shifts in Elevation
B. Shifts Down in Elevation
C. Synchronous Shifts in Elevation

## More…

Responses are often non-linear, showing threshold, complexly interacting, and individualistic trends.

Responses may include local population extirpations, type conversions, mortality events, uncoupled responses, and heightened insect, disease, and fire disturbance.

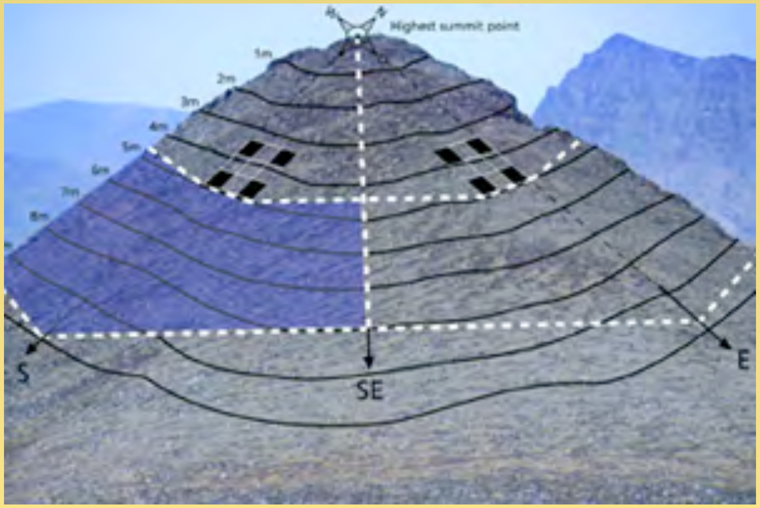
*** ***Simple shifts in elevation of treeline and of plant species and communities are incomplete descriptions of subalpine response to climate*** ***



# Monitoring Changes in the Alpine Zone: GLORIA

The Global Observation Research Initiative in the Alpine Zone

*“To establish and maintain a **world-wide long-term observation network in alpine environments**. Vegetation and temperature data collected at the GLORIA sites are used for discerning **trends in species diversity and temperature**. The data are used to **assess and predict losses in biodiversity and other threats** to these fragile alpine ecosystems which are under accelerating climate change pressures…”*




International Directorate:
Vienna, Austria

Primary nodes within GLORIA International are Target Regions;
Each TR comprises four summits within a similar bioclimatic zone

# North American GLORIA

A CIRMOUNT-Sponsored Program

Six Target Regions Installed in North America;

Four in California: *Tahoe Basin (1), Sierra Nevada (1), White Mtns (2)*




# Early Indications from Baseline GLORIA Installations

- Aspect:  Change in aspect ~ change in elevation
- Diversity: Taxa # varies by TR and substrate
- Exotics: 0-1 species per summit, lowest summit only
- Upper elevation extent varies by substrate (granitic > metamorphic; dolomite > shales/granitic
- Affinities: ~80% are widespread taxa; few are alpine obligates or endemics